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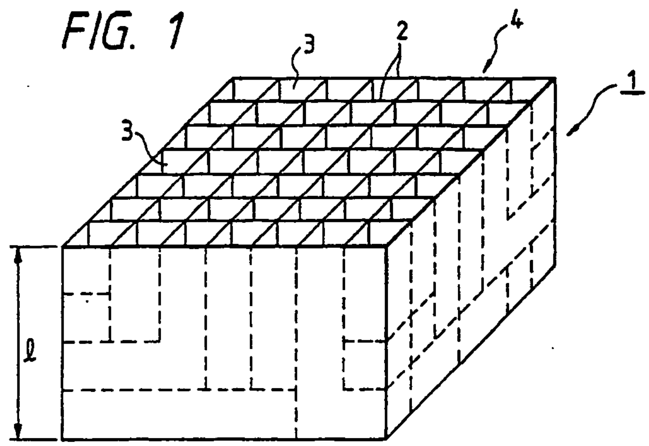
(54) Sound absorber.

(57) A sound absorber body (1) includes a plurality of cell-like spaces (3) defined by walls (2), whose ends are open at a sound absorption side and closed at the other side. The cell-like spaces have different lengths, and part of the cell-like spaces having longer lengths are bent so as to be disposed behind adjacent shorter cell-like spaces. Arrangement of the lengths of the cell-like spaces may be determined in accordance with a two-dimensional quadratic residue series with modulo of a prime number.

FIG. 1



EP 0 405 581 A1

SOUND ABSORBER

BACKGROUND OF THE INVENTION

The present invention generally relates to a sound absorber for use in indoor acoustic design, outdoor noise suppression, and the like, and particularly relates to a sound absorber having a high sound absorption coefficient in a low frequency range.

Conventionally, although various sound-absorbing materials have been used, all the materials have shown a good sound absorption coefficient only in a high frequency range, and the sound absorption coefficient has been exceedingly reduced in the low frequency range of about 125 Hz. Therefore, if used as it is, the conventional sound-absorbing material has not been so effective in absorbing sound in such a low frequency range.

As a sound-absorbing structure in the low frequency range, there have been various proposals of the plate vibration type, the perforated plate resonance type, the porous type having a rear air layer, etc. In the plate vibration type and the perforated plate resonance type, however, the sound absorption coefficient is increased to 0.4 (sound absorption coefficient by the reverberation chamber method) at the most, which is not high enough. In the porous type, on the other hand, although the sound absorption coefficient can be considerably improved by provision of a thick rear air layer, the whole structure becomes large in size; for example, the thickness becomes 60 - 100 cm. The porous type, therefore, is not suitable for practical use. Further, in those sound absorption structures, plywood, a hard board, a plaster board, glass wool, rock wool, and the like are generally used as the material because it is necessary that the acoustic wave internal loss coefficient be large. However, independent use of such materials in the outdoors is difficult because weatherproof properties are required. Moreover, in a hospital, a food factory, or the like, they are hardly used for sanitary reasons (difficulties in sterilization washing).

Recently, problems concerning environmental noises have been regarded as important. In order to provide measures against the noises particularly in a low frequency range, development of a sound absorber having a high sound absorption coefficient in a low frequency range has been desired.

SUMMARY OF THE INVENTION

The present invention has been accomplished in view of the foregoing conditions, and an object thereof is to provide a sound absorber whose sound absorption coefficient in a low frequency range is high, which does not require large establishment space, and which can be used both indoors and outdoors.

The inventors of this application have paid attention to the theory of irregular reflectors by M. R. Schroeder, and have performed various empirical proof tests for the theory. As a result, the inventors have obtained such knowledge that the structure acts as an interference type sound absorber in which acoustic waves different in phase cancel with one another in a frequency range out of the design frequency range and a remarkable sound absorption effect is exhibited particularly in a low frequency range.

The present invention has been accomplished on the basis of the foregoing knowledge, and a sound absorber according to the invention comprises a sound absorber body having an arrangement of a large number of cell-like spaces whose ends are open at one side and closed at the other side, which have different lengths, and part of which having longer lengths are bent so as to be disposed behind adjacent shorter ones.

In the sound absorber having such a configuration as described above, the surface in which the open ends of a large number of cell-like spaces are arranged acts as a sound absorption surface to absorb an acoustic wave, particularly an acoustic wave of a low frequency, incident onto the sound absorption surface. The inventors consider that this is because the phase of the reflected acoustic wave depends on the depth of the reflection position in the cell-like space and resultant acoustic waves different in phase interfere with one another to cause a sound absorption effect.

Here, it is preferable that arrangement of the lengths of a large number of cell-like spaces are determined on the basis of the two-dimensional quadratic residue series, whereby an improved sound absorption effect can be obtained.

The sound absorber has a large number of cell-like spaces different in length, and part of the cell-like spaces having longer lengths are bent so as to be disposed behind adjacent shorter ones, so that the

thickness of the sound absorber can be reduced. Therefore, the establishment space for the sound absorber is reduced accordingly.

Since fundamentally the sound absorber according to the present invention does not utilize a sound absorption effect of a material itself constituting the sound absorber body, it is possible to use, as the material for defining the cell-like spaces, a rigid metal material such as a steel plate causing no acoustic wave internal loss. In this case, problems concerning weatherproof properties and the sanitary problems are not caused, and therefore the sound absorber can be established outdoors or can be used in a hospital and a food factory. The material constituting the body is however not limited to a rigid matter.

Since the above sound absorber is configured such that a plurality of cell-like spaces are opened in the sound absorption surface, dust and the like are likely to come into the cell-like spaces, and it is difficult to clean the cell-like spaces. As a countermeasure to this, the open end surface may be covered with a metal thin film such as stainless steel foil and aluminum foil, or a thin film such as a plastic sheet. It has been confirmed that even if the covering with such a thin film hardly affects the sound absorption effect in a low frequency range. The sound absorber covered with a thin-film is particularly suitable for noise suppression in an operating room of a hospital, a food factory, or the like, since it is easily cleaned and hence is kept sanitary.

Further, in place of such a thin film for covering the open end surface of the sound absorber body, a porous plate such as a glass wool plate, a rock wool plate, a sintered metal plate, and a metal fiber plate may be provided. The provision of such a porous plate is preferable because a high sound absorption coefficient is obtained over the entire frequency range from a low range to a high range. Although the porous plate may be provided as it is, it is preferable to use a porous plate being covered with a plastic film such as a PVF (polyvinyl fluoride) film, which facilitates handling and cleaning of the sound absorber.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic perspective view showing a sound absorber according to an embodiment of the present invention;
Fig. 2 is a plan view of the same sound absorber;
Fig. 3 is a perspective view taken on line III-III of Fig. 2;
Fig. 4 is a schematic perspective view showing a sound absorber according to another embodiment of the present invention;
Fig. 5 shows, in its diagrams (a), (b), (c), and (d), plans of the respective layers constituting the sound absorber of Fig. 4;
Figs. 6 and 7 are schematic perspective views showing further embodiments of the present invention; and
Fig. 8 is a graph showing results of measurement of sound absorption effects.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention illustrated in the accompanying drawings will be described hereunder.

Fig. 1 is a schematic perspective view showing an embodiment of the present invention, and Fig. 2 is a plan view showing the same embodiment. The sound absorber according to this embodiment has a sound absorber body generally represented by reference numeral 1. The sound absorber body 1 has a large number of cell-like spaces 3 defined by walls 2. One end of each of the cell-like spaces 3 is closed and the other end (an upper end in the drawing) is opened. The cell-like spaces 3 are arranged so that the open ends are in the same plane, which works as a sound absorption surface 4. The cell-like spaces 3 are equal in sectional area to one another, but are different in length from one another. Such cell-like spaces are arranged acording to the rule described later. Further, part of the cell-like spaces having longer length are bent so as to be disposed behind adjacent shorter ones as shown in Fig. 3 to thereby reduce the thickness l of the sound absorber. As the material of the walls 2 defining the cell-like spaces 3, it is possible to use a metal material such as a steel plate and aluminum plate, a plastic material, etc.

The respective lengths of the cell-like spaces 3 are selected to be integer times as long as a certain unit length, h. In this embodiment, the arrangement of the cell-like spaces 3 is determined on the basis of the quadratic residue series.

Now, the quadratic residue series will be briefly described. Assuming that p is a prime number and a is an integer which is prime to p. When the following quadratic congruent equation has a solution, it is said that a is a quadratic residue with modulo p.

$x^2 \equiv a \pmod{p}$.

For example, the quadratic residue series is as follows in the case of a prime number p = 7:

$x^2 \equiv a \pmod{7}$.

$x = 0 \Rightarrow 0^2 \equiv 0$

$x = 1 \Rightarrow 1^2 \equiv 1$

$x = 2 \Rightarrow 2^2 \equiv 4$

$x = 3 \Rightarrow 3^2 \equiv 2\ (9 = 1 \times 7 + \underline{2})$

$x = 4 \Rightarrow 4^2 \equiv 2\ (16 = 2 \times 7 + \overline{2})$

$x = 5 \Rightarrow 5^2 \equiv 4\ (25 = 3 \times 7 + \overline{4})$

$x = 6 \Rightarrow 6^2 \equiv 1\ (36 = 5 \times 7 + \overline{\underline{1}})$

From the foregoing, the quadratic residue series in the case of the prime number p = 7 is the one-dimensional series of 0, 1, 4, 2, 2, 4, 1, 0, 1, 4, 2, 2, 4, 1, ... In the two-dimensional case, the quadratic residue series assumes a repetition of the matrix of 7 x 7 shown in Table 1. Here, the horizontal first row and the vertical first column (the left end column) take values of the foregoing one-dimensional series, and each of the remainder positions has a sum value of the values of the corresponding first row and first colunn (in the case where the sum is smaller than 7) or has a value obtained by subtracting a multiple of 7 from the sum (in the case where the sum is larger than 7).

Table 1

0	1	4	2	2	4	1
1	2	5	3	3	5	2
4	5	1	6	6	1	5
2	3	6	4	4	6	3
2	3	6	4	4	6	3
4	5	1	6	6	1	5
1	2	5	3	3	5	2

The length of the cell-like spaces 3 of the sound absorber 1 shown in Fig. 1 is determined on the basis of the foregoing two-dimensional quadratic residue series, and the values written on the open ends of the cell-like spaces 3 in Figs. 2 and 3 are values from Table 1. These values represent the ratio of the lengths of the cell-like spaces 3. For example, the length shown by the value "2" in Fig. 3 represents 2h; "3", 3h; and "6", 6h.

Here, the specific dimensions of the cell-like spaces 3 may be determined with reference to the Schroeder's design conditions for an irregular reflector and in consideration of a desired sound absorption frequency, a desired sound absorption coefficient, an establishment space, a cost, etc. That is, in the Schroeder's irregular reflector designing, the maximum length of the cell-like spaces is designed to be substantially a half of the wavelength corresponding to the design frequency lower limit (irregular reflection occurs in the frequency range not smaller than the lower limit frequency) and the opening side length of the cell-like spaces 3 is designed to be not larger than a half of the wavelength corresponding to the design frequency upper limit (irregular reflection occurs in the frequency range not larger than the upper limit frequency). In the sound absorber according to the present invention, on the other hand, the dimensions of the cell-like spaces 3 may be determined in accordance with its purposes, uses, and the like so that its sound-absorbing frequency range is located outside the Schroeder's design frequency range (irregular reflection range) of the irregular reflector.

The sound absorber body 1 shown in Figs. 1 - 3 may be produced in the form of an integrated body as a whole. The integral formation of the whole body, however, is difficult in production and hence causes a cost increase. Accordingly, it is preferable to produce the whole body from a plurality of divisional parts. For example, the sound absorber body 1 may be produced such that blocks each having one or a plurality of cell-like spaces are first produced and the blocks are suitably combined with one another to constitute the sound absorber body 1. Alternatively, the sound absorber body 1 may have a structure of four layers 1a, 1b, 1c, and 1d as shown in Fig. 4. In this latter case, the sound absorber body 1 is produced such that the

four layers are produced separately and then integrated to form the sound absorber body 1. In this four-layer structure, the layers 1a - 1d have structures shown in the diagrams (a), (b), (c), and (d) of Fig. 5, respectively. The portions illustrated by hatching 5 in the diagram (a) of Fig. 5 show walls formed on upper surfaces of the cell-like spaces 3 so that the length of the cell-like spaces 3 of these portions is made to be zero, and the portions illustrated by hatching 6 in the diagrams (a) - (d) of Fig. 5 represent bottom walls.

Each of the sound absorber bodies 1 of Figs. 1 and 4 can be used as a sound absorber as it is. That is, a large number of sound absorber bodies 1 are arranged so that the sound absorption surfaces 4 form the same plane which is to become a sound absorption wall.

Fig. 6 shows another embodiment of the present invention. In this embodiment, a thin film is provided on the sound absorption surface 4 of the absorber body 1 of Fig. 1 so as to cover the open ends of the cell-like spaces 3 of the sound absorber body 1. As the thin film 7 used in this embodiment, it is possible to use a metal thin film such as a stainless steel film and an aluminum film, a plastic sheet, etc. The provision of such a thin film 7 on the sound absorption surface 4 as illustrated in this embodiment facilitates cleaning of the sound absorber 1.

Fig. 7 is a further embodiment of the present invention. In this embodiment, a porous plate 8 is provided on the sound absorption surface 4 of the sound absorber body 1 of Fig. 1 so as to cover the open ends of the cell-like spaces 3 formed in the sound absorber 1. As the porous plate 8 to be used in this embodiment, it is possible to use a glass wool plate, a rock wool plate, a sintered metal plate, a metal fiber plate, and the like as it is or with a covering plastic film. Alternatively, in place of the porous plate 8, a perforated plate material of a hard board, a plaster board, plywood, and the like may be used.

A large number of sound absorbers of Fig. 6 or 7 may also be arranged side by side to constitute a sound absorption wall.

Next, description will be made as to the results of sound absorption tests which were performed by using the following examples of sound absorbers according to the present invention.

EXAMPLE I

Only one sound absorber body 1 of the four-layer structure as shown in Figs. 4 and 5.

Outside dimensions: 50 cm x 50 cm x 28 cm (thickness)

Sectional size of a cell-like space: 70 mm x 70 mm

Unit length of a cell-like space, h: 70 mm

Length and arrangement of cell-like spaces:

according to the two-dimensional quadratic residue series of the prime number = 7

Used material: steel plate of 0.7 mm thickness

EXAMPLE II

The open end surface of the sound absorber body of Example I was covered with a stainless steel thin film (200 µm thickness). See Fig. 6.

EXAMPLE III

The open end surface of the sound absorber body of Example I was covered with a glass wool plate (32 kg/m^3 density and 10 mm thickness. See Fig. 7.

COMPARATIVE EXAMPLE

The glass wool plate itself used in Example III.

The reverberant sound absorption coefficients of the foregoing four kinds of test pieces were measured according to JIS-A1409. Table 2 and Fig. 8 show the results of measurements.

Table 2

Frequency (Hz)	Example I	Example II	Example III	Comparative Example
125	0.93	1.37	1.38	0.04
160	0.79	1.10	1.42	0.09
200	0.99	0.70	1.28	0.11
250	1.02	1.06	1.25	0.14
315	0.94	0.85	1.28	0.19
400	0.70	0.77	1.11	0.21
500	0.97	0.77	1.25	0.28
630	0.89	0.57	1.07	0.38
800	0.87	0.51	1.09	0.47
1000	0.61	0.39	0.98	0.58
1250	0.32	0.31	0.87	0.60
1600	0.30	0.25	0.92	0.66
2000	0.20	0.20	0.84	0.70
2500	0.20	0.23	0.80	0.75
3150	0.23	0.19	0.90	0.76
4000	0.29	0.16	0.91	0.81

As seen from Table 2 and Fig. 8, Example 1 showed a high sound absorption coefficient not only in the low frequency range (about 315 Hz) but in the intermediate range (800 Hz).

Example II showed a high sound absorption coefficient substantially the same as Example I in the low frequency range though it has a slightly lower coefficient than Example I in the intermediate range. Therefore, the sound absorber of Example II has sufficient practicality, specifically when sanitary reasons are taken into account.

Example III showed a high sound absorption coefficient in the entire frequency range. As will be well seen from comparison with Comparative Example, the sound absorption coefficient of Example III in the low frequency range is remarkably improved, while the glass wool plate itself merely shows a low sound absorption coefficient over the frequency range from the low range to the intermediate range. Therefore, if a glass wool plate coated with a plastic thin film such as a PVF (polyvinyl fluoride) film is combined with the sound absorber, an excellent sound absorption apparatus having good weatherproof properties can be realized.

Although the cell-like spaces 3 formed in the sound absorber body 1 are illustrated to have a regular square section in the foregoing embodiments, the cross section is not limited to that one, but may be selected to be rectangular, triangular, circular, or the like. Further, although in the foregoing embodiments a plurality of cell-like spaces 3 are arranged such that the open ends thereof are disposed in the same plane, it is not always necessary to dispose the open ends in the same plane, but the cell-like spaces 3 may be arranged with their open ends displaced in their longitudinal direction.

As described above, the sound absorber according to the present invention shows a high sound absorption coefficient (for example, about 0.9) over the frequency range from the low range to the intermediate range without much increasing the thickness of the sound absorber (for example, about 30 cm). Further, it is possible to use a metal material such as a steel plate and an aluminum plate, so that the sound absorber according to the present invention is easy in production and excellent in weatherproof property. Furthermore, reduction in weight can be obtained by using a plastic material. The sound absorber according to the present invention, therefore, has an advantage that it can be very effectively used for an indoor or outdoor sound absorption structure for absorbing sound in the low frequency range.

Further, the sound absorber in which the open end surfaces of the cell-like spaces are covered with a metal thin film such as stainless steel foil and aluminum foil, or a thin film such as a plastic sheet, is suitable for noise suppression in an operating room of a hospital, in a food factory, and the like, because the sound absorber is easily cleaned and therefore is kept sanitary.

Moreover, the sound absorber in which a porous material is provided on the open end surfaces of the cell-like spaces can be utilized as a very excellent sound absorber because such a sound absorber shows a high sound absorption coefficient over the entire frequency range from the low range to the high range.

Claims

1. A sound absorber characterized in that:
a sound absorber body comprises a plurality of cell-like spaces arranged in parallel, whose ends are open at a sound absorption side and closed at the other side;
the cell-like spaces have different lengths; and
part of the cell-like spaces having longer lengths are bent so as to be disposed behind adjacent shorter cell-like spaces.

2. A sound absorber according to claim 1, wherein arrangement of the lengths of the plurality of cell-like spaces is determined in accordance with a two-dimensional quadratic residue series with modulo of a prime number.

3. A sound absorber according to claim 1, wherein each of the cell-like space is square in section.

4. A sound absorber according to claim 1, wherein an end surface of the sound absorber body at the sound absorption side is covered with a thin-film.

5. A sound absorber according to claim 4, wherein the thin-film is a metal thin-film.

6. A sound absorber according to claim 1, wherein a porous plate is provided on an end surface of the sound absorber body at the sound absorption side.

7. A sound absorber according to calim 6, wherein the porous plate is covered with a plastic film.

8. A sound absorber according to claim 1, wherein a perforated plate is provided on an end surface of the sound absorber body at the sound absorption side.

9. A sound absorber according to claim 1, wherein the sound absorber body is constituted by a plurality of divisional layers which are perpendicular to a longitudinal direction of the cell-like spaces.

10. A sound absorber according to claim 1, wherein the plurality of cell-like spaces are defined by metal walls.

FIG. 1

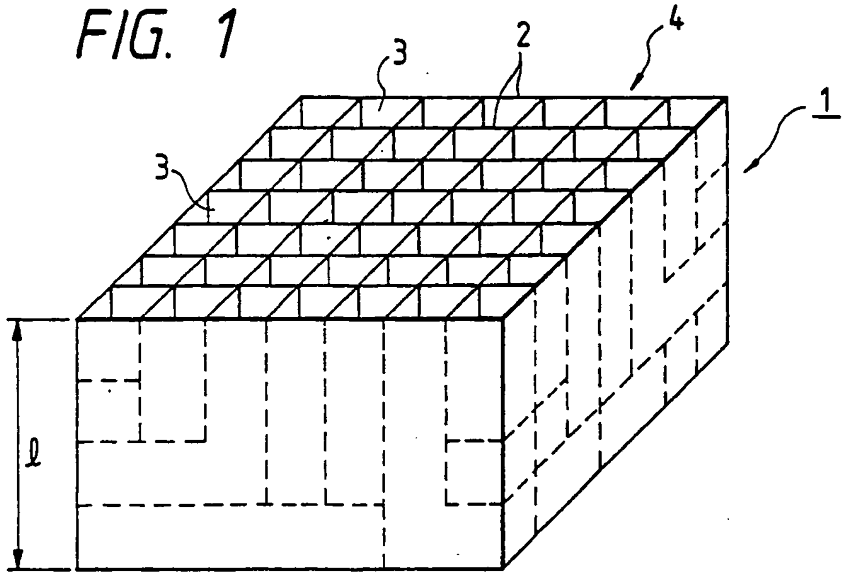


FIG. 2

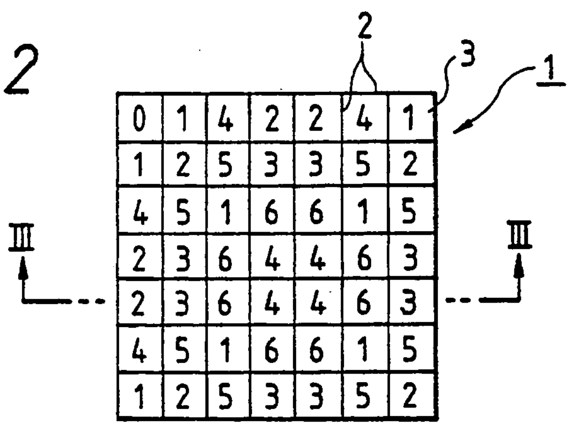


FIG. 3

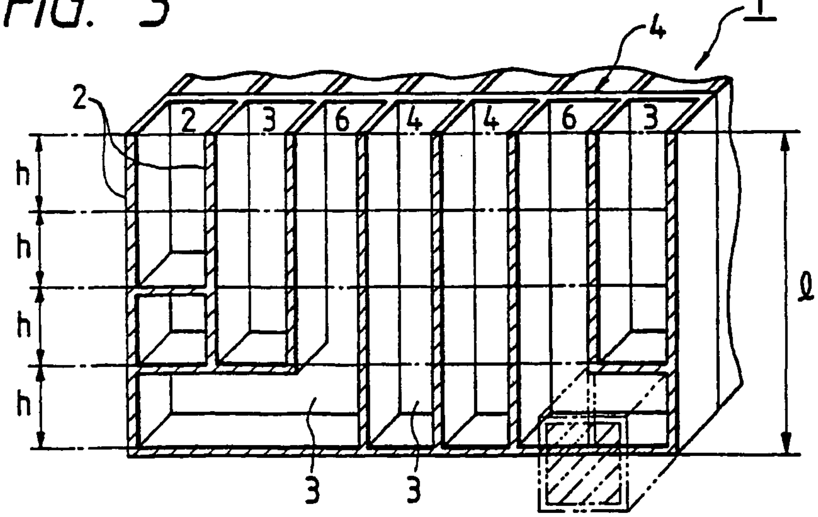


FIG. 4

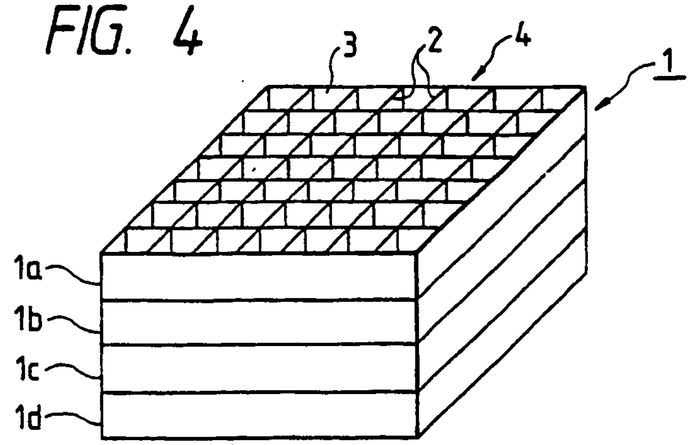


FIG. 5(a)

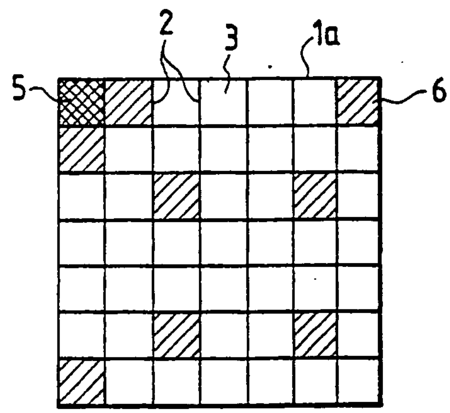


FIG. 5(b)

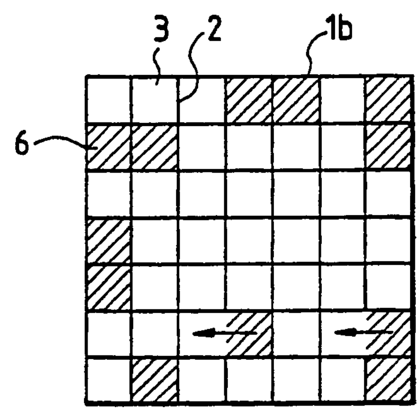


FIG. 5(c)

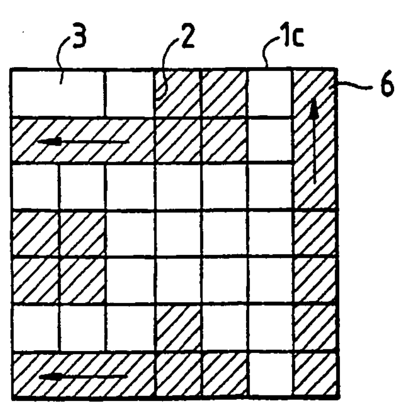


FIG. 5(d)

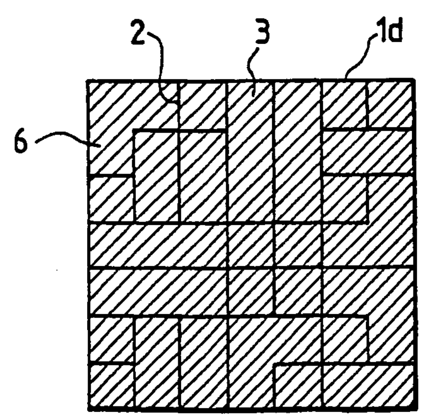


FIG. 6

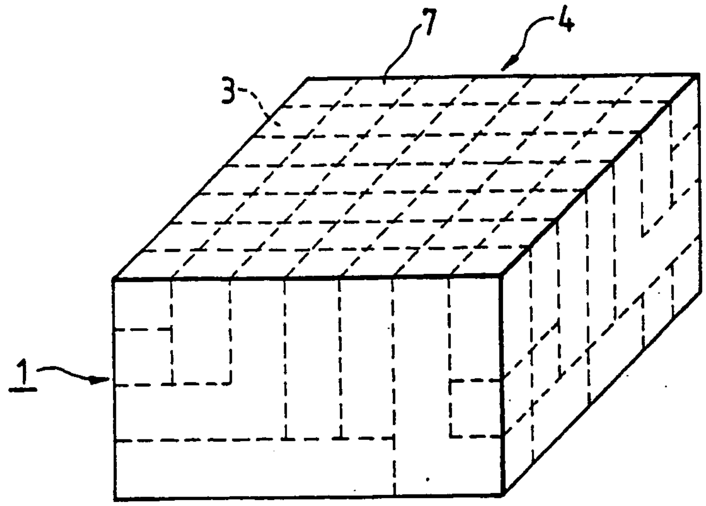


FIG. 7

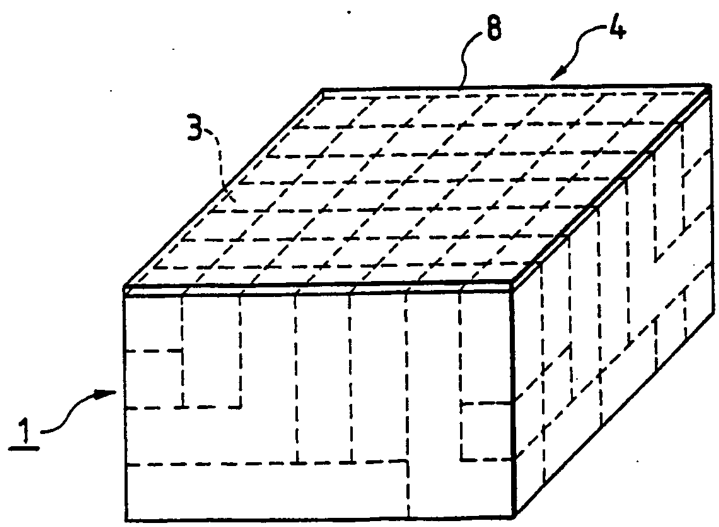
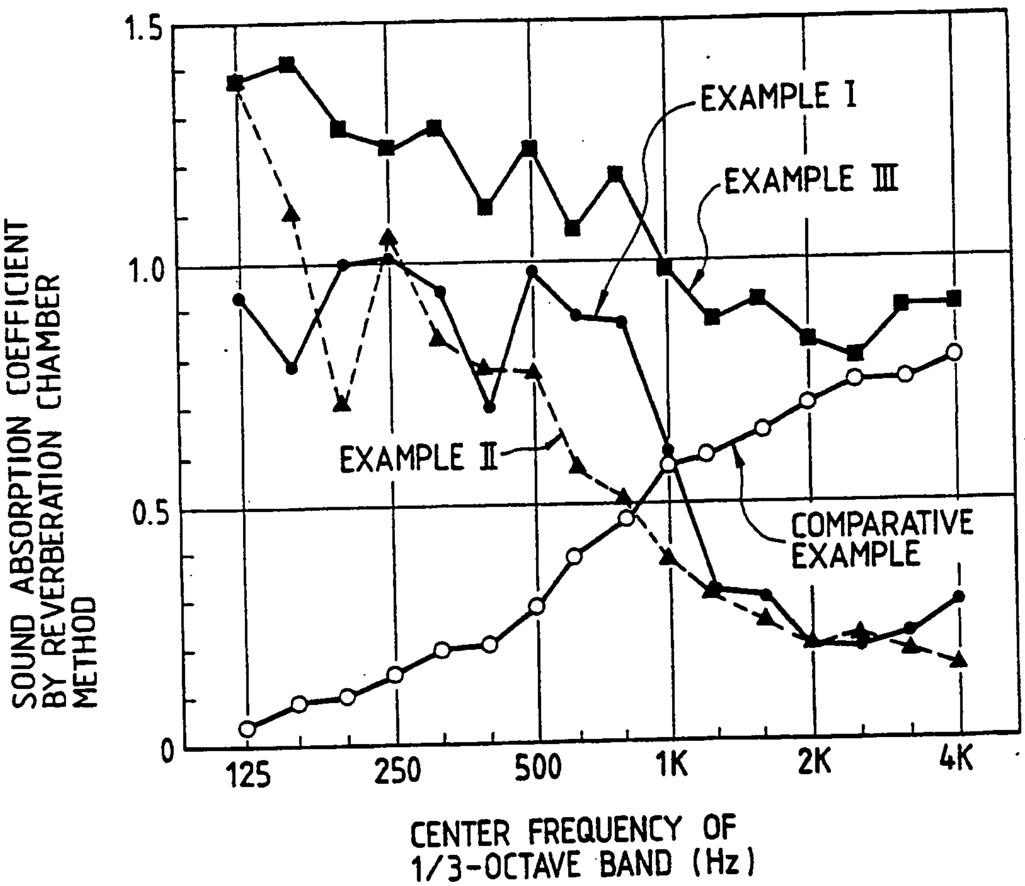


FIG. 8


1.5
1.0
0.5
0
125
250
500
1K
2K
4K
EXAMPLE I
EXAMPLE III
EXAMPLE II
COMPARATIVE EXAMPLE
SOUND ABSORPTION COEFFICIENT BY REVERBERATION CHAMBER METHOD
CENTER FREQUENCY OF 1/3-OCTAVE BAND (Hz)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 11 2461

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	FR-A-2214932 (LOCKHEED AIRCRAFT CORPORATION) * page 3, line 37 - page 4, line 29 *	1, 3, 8	E04B1/84 G10K11/16
Y	* page 6, line 18 - page 7, line 12 * * page 8, line 37 - page 9, line 40; figures 1-3, 7 *	4-6, 10	
Y	US-A-1972563 (RICHARD IRVING) * page 1, lines 43 - 77; figures 1, 2 *	4, 5	
Y	US-A-3693750 (PHILIP D. TAKKUNEN) * column 4, line 44 - column 5, line 3; figure 4 *	6	
Y	US-A-4384020 (STANLEY L. BEGGS ET AL.) * column 1, line 48 - column 2, line 26; figures 1, 2 *	10	
A		6, 7	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

E04B
G10K

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19 SEPTEMBER 1990	BARBAS A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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1